OPTICAL DETECTION OF MEALINESS IN APPLES BY LASER TDRS

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Abstract

Mealiness is a quality-impairing textural disorder, combining softness and absence of free juiciness. The only current test is destructive; it combines information from a mechanical probe test to classify the samples according to instrumental mealiness. Time-domain laser reflectance spectroscopy (TDRS) can assess simultaneously and independently the absorption of the light inside the irradiated body (μa coefficient) and the scattering of the photons across the tissues, μ's, transport scattering coeff.) at each wavelength. With VIS and NIR lasers as light sources, TDRS was applied to Golden Delicious and Cox's apples (n=90), forming batches of untreated and storage-treated (20ºC & 95%RH) samples to induce mealiness. The collected data were clustered into groups according to their instrumental mealiness values. Three to seven optical coefficients were used as independent variables when building discriminant functions, which correctly identified 75-89% of mealy apples.

1. Introduction

Mealiness is a negative fruit texture attribute that combines the sensation of a disaggregated tissue with lack of juiciness. It is associated with late harvest and long-term storage, but its development may be accelerated by temperature treatments and high relative humidity (De Smedt, 2000). A recent EC Project (FAIR CT95-0302) compared sensory panel evaluations with instrumental measurements, in assessing mealiness in apples, peaches and tomatoes. Use of a mechanical test involving confined compression by probes has been proposed as the basis for redefinition of mealiness in apples and peaches by relating rheological properties to human perceptions of mealiness (loss of crispness, hardness and juiciness) (Barreiro *et al.,* 1998). TDRS or TRS (time-domain resolved spectroscopy or time reflectance spectroscopy) has been developed in the field of medicine for the detection of discontinuities in tissues. In the present study, the objective was to apply TDRS for the non-destructive internal detection of mealiness in apples.

2. Materials and methods

The following samples were prepared (Table 1):

A. Apples with "natural mealiness", to determine whether it is present in late-harvested apples: Golden Delicious apples were picked in Zaragoza, Spain in the last week of October 1998. From the whole harvest, 25 fresh (*a priori* non mealy) and 25 possibly (*a priori)* mealy fruits were packed and sent to Milan in November. The "*a priori* mealy" samples were selected according to two subjective criteria: external color (mealy batch more golden than the fresher one) and tactile hardness.

B. Apples with mealiness induced by chamber storage: 20 Belgian Cox's apples that had been harvested early were stored until November inside an ultra-low oxygen

(ULO) chamber to preserve their freshness; another 20 apples were kept for 16 days at 20ºC and 95% relative humidity, to induce mealiness. Not all of the latter batch were expected to become mealy.

The tests carried out on the samples, in chronological order, were:

TDRS measurements:

TDRS is based on the measurement of the broadening of a short light pulse, transmitted across a turbid medium. Light from a tuneable laser is injected into the fruit through the intact skin. A suitable theoretical model makes it possible to calculate the absorption coefficient and the transport scattering coefficient at each wavelength (Cubeddu *et al.,* 1994a; Cubeddu *et al.,* 1994b; Cubeddu *et al.,* 1999). In the present study, the optical coefficients were determined at several wavelengths on both sides of each sample. The wavelength ranges covered were: far VIS (visible: 672, 750 and 818 nm) and NIR (near infrared: 900-1000 nm in 10-nm steps).

Confined compression test:

By means of a texture analyser, cylindrical fruit probes of 1.7 cm height and diameter confined in a ring were pressed against a flat base, to obtain a deformation of 2.5 mm at 20mm/min, when they were immediately removed; two replications were made per fruit (one each side) and the average parameters were used for the analyses. A piece of filter paper was placed beneath the specimen, to recover the juice extracted during the test. Some of the parameters registered were: maximum force/deformation (N), hardness expressed as the slope of curve (N/mm, notation "SLOPE1LU"), juice area on the paper (mm^2, notation "JUICEARE").

3. Results

The data obtained from the confined compression measurements were used to classify the samples in one of the three following classifications: a) two textural categories ("mealy", vs. "fresh"); b) three ("mealy", "non-mealy" = dry or soft, "fresh"); or c) four ("mealy", "dry" but firm, "soft" but juicy, "fresh"). A sample was labelled as "soft" when SLOPE1LU<20 N/mm; it was "dry" if JUICEARE<4 cm^2; a "mealy" sample has to be soft and dry. A first comparison can be done between *a priori* and destructive classification, as shown in Figure 1.

Discriminant analysis functions were built using the TDRS coefficients as independent variables to classify the fruits in two, three or four textural categories. *A priori* classification probabilities were calculated as proportional to group sizes, and classification functions were modeled with a stepwise approach. A first model (Table 2) was created with both varieties pooled together to discriminate between "mealy" and "fresh". Seven TDRS variables were used in the model (both absorption and scattering, at the chlorophyll absorption peak – 670 nm – and six NIR wavelengths), which achieved a success rate of 85.0% in correctly classifying fruits. Among misclassifications, there was a higher proportion of mealy samples predicted as fresh (8/21), than the reverse (5/56).

The segregation capability of this type of model was validated by alternatively using half of the samples as the learning subset and the rest as anonymous. A randomization procedure was used to generate the subsets, based on a distribution of 33 fresh plus 13 mealy per group. The score of well classified samples ranged from 88.9 to 75.6%, with the worst performance obtained for the "mealy" class.

The inclusion of increasing textural categories in the new models led to considerably reduced performance compared with the two-class model. The model discriminating among "fresh", "dry", "soft" and "mealy" scored 73.3%of well classified fruits in both varieties, whereas a model with three classes ("fresh", "non-mealy" and "mealy") achieved 72.2%. In both cases it was noticed that the intermediate classes ("dry", "soft" or their combination, "non-mealy") were the worst predicted groups. Models developed for each variety separately were more accurate than for those handling pooled data from both varieties.

In order to reduce the number of variables in the models, new analyses were performed with more restrictions on the number of wavelengths and the tolerance level of the stepwise method. It was seen that the remaining variables in the models were all absorption coefficients, and all the scattering ones were removed in the stepwise algorithm. The wavelengths stayed in the same areas stated above. A five-variable model achieved 84.4% and a three-variable model scored 83.3%.

Discussion

The process of obtaining mealy samples is not always straightforward. Not all Cox samples stored under strict relative humidity and temperature conditions expected to induce mealiness were mealy at the end of the treatment. On the other hand, it seems clear that late-harvested Golden Delicious apples may develop mealiness on the tree. This is of great importance for apple growers in some areas.

Predictive models based on TDRS absorption and scattering coefficients, developed for identifying two mealiness states, showed high discrimination performance (95% of fruits correctly classified), when classifying samples of both apple varieties. The stability of this performance in the validation processes was good.

Models estimating more than two states offered much lower accuracy. The prediction of three and four levels of mealiness achieved 72 and 73% success, respectively in classifying fruits. These figures are not a suitable basis for a classification technique. The fact that the highest misclassification scores were found in the intermediate groups (fruits other than fully mealy or fully fresh) suggests that the technique is not in itself adequate to detect the changes in the individual quality parameters involved in the development of mealiness (apparent drying of tissues, softening) but it is useful for detecting the combined effects of these changes. This inadequacy could be a problem related to the system setup or could be a matter of detection resolution. The trial with fewer variables in the models was satisfactory: performance deteriorated by only 2% in moving from the model with seven variables (correspondent wavelengths) to the last model with three variables and wavelengths. This point will be of great importance in adapting the system to fit industrial requirements of low cost, ease of operation and stability.

Conclusions

Time domain reflectance spectroscopy has been proven to be a useful technique for the non-destructive identification of mealiness in apples. Error rates in classification models discriminating between mealy and non-mealy samples were acceptable. The segregation among more than two textural levels of mealiness (other than "fresh" and "mealy") has not been achieved so far, and requires more studies. The technique, new in the field of food sensors, shows interesting potential as a stand-alone non-destructive technique for internal monitoring of parameters related to quality attributes and disorders. Further development is planned for its integration into an automatic classification system.

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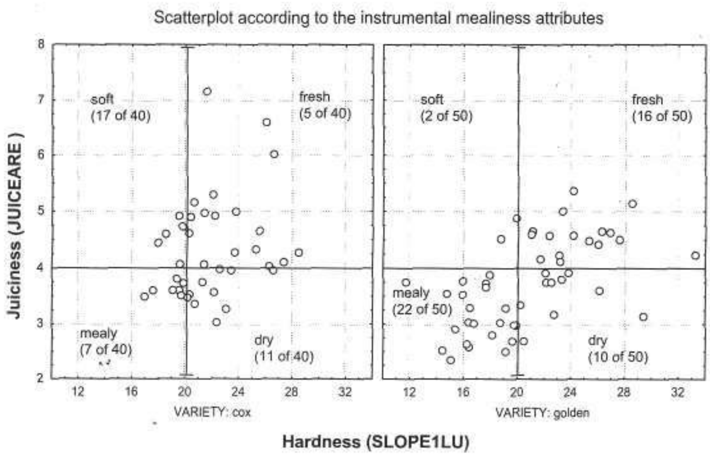
Tables

1. Samples measured, harvest/storage treatment, expected (*a priori*) textural state and wavelengths measured with TDRS equipment. Magness-Taylor penetration ranged from 16 to 22 N for Cox and from 14 to19.5 N for Golden Delicious.

Apple	# f	Origin	Treatment	Expected state	TDRS wavlgths Far VIS (nm)	TDRS wls NIR(nm) (each 10nm)
Cox	20	Belgium	ULO storage	"fresh"	672, 750, & 818	900-1000
Cox	20	Belgium	RH 95%, 20ºC, 16 days	"mealy"	672, 750, & 818	900-1000
Golden D	25	Spain	Late harvest	"fresh"	672, 750, & 818	900-1000
Golden D	25	Spain	Late harvest (overripe)	"mealy"	672, 750, & 818	900-1000

2. Classification matrix for apples (Cox's & Golden) as "mealy" or "fresh" (=not mealy). Rows: Observed. Columns: Predicted. p = *a priori* probabilities.

	Percentage correct	fresh p=.68	mealy p=.32
fresh	91.80%	56	5
mealy	72.41%	8	21
Total	**85.56%**	64	26



Hardness vs. juiciness of all samples; discriminating limits for "dry" textural category, "soft" and the combination of both ("mealy") are drawn.